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PERFORMANCE EVALUATION OF DRAINED PAVEMENT STRUCTURES

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16. Abstract

This research study focused on positive drainage of pavement structures. The open-graded base course concepts included non-stabilized, asphalt cement concrete (AC) stabilized and Portland Cement (PCC) stabilized. Drainage systems included pipe in trenches, fin-type, pipe beneath transverse joints and retrofitted pipe. Non-drainage elements included 3.05m (14 foot) wide driving lanes, and a 30.48cm (12 inch) layer of “select embankment.” Twelve projects were monitored, both Portland cement concrete surface and asphaltic concrete surface. Measurement surveys included Pavement Distress Index (PDI), transverse joint faulting, International Roughness Index (IRI) ride quality and coring at the transverse joints. The analysis revealed the three dominant features for PCC to be: asphalt stabilized open-graded base course, doweled transverse joints and select embankment. The effects of the three in combination were not additive, which questioned the need to have two of the three elements in the same pavement structure. The coring revealed that asphalt stabilized open-graded base course had stripping at transverse joints, which questioned its long term efficacy. Cost-benefit analysis indicate an additional nine years of performance was needed to maintain a positive cost-benefit ratio if an asphalt stabilized open-graded base course was included in a pavement structure, whereas only 1 to 2 years of additional performance were needed when just dowels were used. The AC over asphalt stabilized open-graded base course structure provided better pavement performance than other AC sections. Retro-fitted edge drains and TIC drains appeared to have little benefit. Open-graded base course gradation #1 had similar pavement performance to #2. Unsealed PC transverse joints provide pavement performance equal to that of sealed joints. Three recommendations were that (1) the existing study or test sections be evaluated for at least 5 more years in order to determine possible long range benefits of open-graded base course; (2) Wisconsin #2 open-graded base be given serious consideration for all open-graded projects, and, (3) additional projects be constructed to determine the efficacy of AC pavement over open-graded base.

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RESEARCH PROJECT # WI 87 - 05

FINAL REPORT WI/SPR-04-98

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ABSTRACT

The presence of excess water in pavement structures causes a progressive weakening of the structure and subgrade. This produces a greater susceptibility to damage of the pavement structure by heavy loading and environmental factors and results in decreased pavement serviceability. This research study focused on positive drainage of pavement structures which was considered to promote greater pavement performance. The objectives of the study were to determine:(1) which features have the greatest impact on pavement serviceability; (2) which features were most effective in draining excess water from the pavement structure; (3) which features were the most cost effective; and secondarily (4) whether transverse joint sealing was effective.

Five primary Portland Cement concrete (PCC) surfaced projects were included in the initial study. During the course of the study, seven other projects using positive drainage elements had been constructed and were selected to be included in the monitoring as "secondary" projects. Three of the secondary projects were PCC, three were asphaltic cement concrete (AC) surfaced, and one project had both PCC and AC test sections. Within each project site, a control section and one or more test sections were developed to compare various combinations of drainage and transverse joint load transfer concepts. Positive drainage elements were incorporated into both primary and secondary projects by initial design for new pavements and as a result of retrofitting for existing pavements. A further comparison was made of undoweled transverse joints and doweled transverse joints.

The drainage concepts that were compared included the standard (at that time) dense-graded base course, non-stabilized open-graded base course, asphalt cement stabilized open-graded base course and Portland Cement stabilized open-graded base courses. Drainage systems included various configurations of longitudinal edge drains with perforated pipe in geotextile-wrapped aggregate filled trenches, fin-type systems, and the Transverse Inter-Channel (TIC) system of perforated pipe drains beneath each transverse joint. The edge drain systems used geotextile fabric to encase either the drain pipe or the trench.

Other elements were included in the project pavements as a matter of expanded design policy or construction expediency and became unintended variables. These were 3.05m (14-foot) wide driving lanes which were traffic stripped at 3.66m (12 feet), and the use of a 30.48cm (12 inch) layer of "select embankment" consisting of rock produced by blasting outcroppings during base preparation. The select embankment was in place for approximately two years to the placement of the pavement structure.

Pavement measurement surveys taken on the project sites included Pavement Distress Index (PDI), transverse joint faulting, ride quality using the International Roughness Index (IRI) and coring at the transverse joints. The survey data indicated adequate ride quality with very little distress in PCC pavements, except that of minimal early transverse joint faulting in the undoweled joints. This resulted in low PDI values with transverse joint faulting identified as the major contributor. The coring revealed that the asphalt stabilized open-graded base course had experienced stripping at transverse joints and brought into question the long term efficacy of asphalt stabilized open-graded base course.

The analysis of the measured historical data included the statistical paired-t test. The test revealed that asphalt stabilized open-graded base course test sections were always found significantly better than the control in either IRI, PDI or transverse faulting. Test sections of the other open-graded base course's had a mixed comparison to their respective control sections through the statistical test. It was not possible to make comparisons of doweled test sections with non-doweled sections through the paired-t test since some projects had only one doweled test section and other projects had all doweled test sections.

The 1997 survey data for PDI, transverse joint faulting and IRI were ranked by test value to determine which variables had the greatest impact on pavement performance. The ranking indicated that the presence of dowels, asphalt stabilized open-graded base course or select embankment exerted a dominant influence. The effect of dowels, select embankment or asphalt stabilized open-graded base course on the performance of the test sections masked the effect of any other variable, negating other comparisons. This influence, which appears to be similar for each of these three dominant elements individually, does not appear to be cumulative when these elements were in combination. Therefore, any one of the three would produce the positive effect desired.

Other more marginal effects were discernible from the 1997 rankings of PDI, transverse joint faulting and IRI. There appeared to be only a marginal difference in favor of positively drained test structures as opposed to non-drained structures. The ranking did not indicate a definite benefit to PDI due to the presence, absence or type of edge drain. The effect of cement stabilized open-graded base course and non-stabilized open-graded base course verses dense-graded base course on PDI was not noticeable or was masked by the presence of dowels and select embankment. Sawing the long slabs of the random sequence shortened slabs and retro-fitting edge drains in the project area had no effect on the IRI. The post-construction of retrofit edge drain systems appear to perform similar to an undrained dense-graded base course for IRI. The presence of TIC drains did not appear to be beneficial to IRI.

Test sections with unsealed PCC transverse joints appeared to provide pavement performance equal to that of sections with sealed joints. This finding supported that of an earlier comprehensive WISDOT research study of extremely long duration which was concluded during the course of a joint sealing study. This earlier study resulted in a Departmental policy of not sealing transverse joints on the state trunk highway system.

The PDI and IRI survey data from three of the four secondary AC projects appeared to be ambiguous. Projects with low IRI values also have high PDI values, and the contrary (vice versa).

However, on the fourth project, the data implies that the AC over asphalt stabilized open-graded base course structure was providing better pavement performance than that of the other sections. It would be advantageous to have more test sections on which to base support for definitive conclusions based on this research concept.

The initial thrust of this research was to determine the efficacy of positive drainage on PCC pavement structures. The dominant features which were not construction expediency, were seen through the test section data measurements to be asphalt stabilized open-graded base course and doweled transverse joints. The research gives strong indication that individual effects of dowels and asphalt stabilized open-graded base course were equal. The research implies that in combination, the effects were not additive. The indication of powerful and equal influence shown by test sections using dowels and test sections using asphalt stabilized open-graded base course questions the need to have both elements in the same pavement structure. It is the policy of the WisDOT to have dowels and non-stabilized open-graded base course in the structure of all state trunk highway PCC pavement structures. Analysis of historical cost-benefit data indicate that an additional 9 years of pavement performance is needed to maintain a positive cost-benefit ratio if an asphalt stabilized open-graded base course is included in a pavement structure, whereas only 1 to 2 years of additional adequate pavement performance are needed for dowels.

It appears after 10 years of observation that dense-graded base course with doweled pavement is equivalent to open-graded base course with doweled pavement. Dense-graded base with doweled pavement was shown to be as structurally effective and more cost effective than asphalt stabilized open-graded base course with doweled pavement.

The data presented in this report indicates that Wisconsin DOT open-graded base course gradations #1 and #2, and dense-graded base course have resulted in the same pavement performance for PCC pavement with dowels. It is therefore cost effective that the less expensive and more trafficable open-graded base course gradation #2 be given primary consideration when open-graded base courses are used.

The specialized nature of the test sections that used AC on open-graded base course in this study precluded definitive comparisons. It is recommended that the pavement management files be reviewed for the performance of AC on open-graded base course. If the data is lacking, it is recommended that technology advancement projects be developed to determine the efficacy of AC over open-graded base course structures.

It is recommended that the existing study projects (or test sections) be evaluated for at least 5 more years in order to determine possible long range benefits of open-graded base course that may not be apparent at this time.

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BACKGROUND

Historical evidence indicates that the presence of water in the pavement structure appears to cause a progressive weakening of the structure and subgrade. This produces a greater susceptibility to damage of the pavement structure from heavy traffic loading and environmental factors such as extended rain events and results in decreased pavement serviceability. A research study was proposed and a work plan developed in 1988 which included elements that purported to provide positive drainage of pavement structures and thereby promote greater pavement performance.

The objectives of the study were to determine:

(1) which features have the greatest impact on pavement serviceability,
(2) which features were most effective in draining excess water from the pavement structure,
(3) which drainage features were the most cost effective, and
(4) whether transverse joint sealing is effective.

Candidate projects were selected in various locations of the state (Figure 1). There were six primary Portland Cement Concrete (PCC) projects (Table 1). The first project, USH 14 in Dane County, was constructed in 1987. The other primary projects were constructed in 1988. These included USH 18-151, (Drain Study), Iowa County; USH 18-151, Dane County (Transverse Dowel Study adjacent to USH 18-151 Iowa County project); STH 29, Brown County; STH 50, Kenosha County; and STH 164, Waukesha County.

Test sections and control sections were developed within each project site. The test sections were used to compare various formats of positive drainage features. These positive drainage features were to be incorporated both by initial design for new pavements and as a result of retrofitting when existing pavements were used. The control sections contained no positive drainage elements.

Secondary PCC and asphaltic cement concrete (AC) studies (Table 2) researching positive drainage concepts were also begun previous to or during this study, but on a less comprehensive scale. It was considered beneficial that this report should also describe the results of these secondary research projects. The PCC projects were: (1) IH 43, Ozaukee County, featuring TIC drain variations and surface grind, retrofit 1989; (2) USH 151, Dane County (1991 Open House), featuring the various open-graded base course types of this study plus the “New Jersey” type defined later in the text, construction 1991; and (3) IH 43, Walworth County: featuring retrofit edge drains, surface grind and reconfigure slab lengths, construction 1992.

The secondary AC projects were: (1) STH 60 (Grafton Rd), Washington County (construction 1990), featuring various open-graded base course type combinations including the WisDOT open-graded #2; (2) STH 167 (construction 1990), (Mequon Rd), Washington County, compared non-stabilized open-graded base course to dense-graded base course with TIC drains, (3) USH 151, Dane County (1991 Open House), featuring an AC surface on dense-graded base and an AC surface on asphalt stabilized open-graded base, construction 1991; and (4) STH 73, Columbia County, a low ADT facility with low truck traffic, featuring AC pavement over non-stabilized No.#1 stone with longitudinal edge drains; construction 1985.

The positive drainage features included open-graded base courses. The Wisconsin DOT has developed two open-gradation bases. The open-graded base used primarily in this study was Wisconsin #1, which had a 3048m (10,000-foot) per day permeability for rapid water elimination. It was felt that rapid drainage was essential for most of the projects used in this study. WisDOT restricts using #1 on construction haul roads since this gradation, using the fractions of larger stone, tends to rut easily. Wisconsin #2 has a higher density gradation which provides 152.4m (500-foot) per day permeability. Wisconsin #2 can be produced more economically than #1 and traffic can be allowed on #2 because of the greater stability. However, at the time of this study, it was felt that Wisconsin #2 should be used only where essential service access had to be maintained, preferring stability over permeability. Wisconsin #2 was used on only one test section. Another open-base gradation used was termed the "New Jersey" gradation and was similar to Wisconsin #2. This gradation was also used on only one test section.

The open-gradation bases described above were termed non-stabilized bases. As a further research consideration, some of the open-graded base courses were stabilized with asphalt cement or Portland Cement. These bases and the non-stabilized bases were compared to control sections having a standard dense-graded base course. In the balance of this report, when the term such as asphalt stabilized open-graded base course is used, it will refer to a pavement structure having asphalt stabilized open-graded base course as the emphasized main feature.

Moisture sensors were installed within the pavement structure of the primary projects in a redundant array 15.24m (50 feet) apart in the dense-graded base course just below the dense-graded base course / upper layer interface. The sensors acquired data with respect to rainfall intensity and duration, saturation duration and edge drain outfall. Analysis of the sensor responses was anticipated to reveal distinct differences when comparing non-drained dense-graded base course to positive drainage systems. It was also expected that insights would be gained into periods of base course saturation, and the effect that longitudinal pavement profile, transverse pavement profile and joint location had on pavement drainage. A contract was developed with the United States Geological Survey Department to serve as consultant for this effort. The United States Geological Survey was to install the equipment and acquire and reduce the data.

The longitudinal edge drain systems were most commonly installed along the edge of the pavement after the pavement was placed. Four types of longitudinal edge drain systems were tested in the primary projects. The standard system was a 15.24cm (6-inches) slotted pipe in an aggregate filled trench cut through an open-graded base layer, placed after the pavement was constructed. The trench was usually wrapped with a geotextile. A second system (retro) used a slotted pipe wrapped in a geotextile sock and placed in a trench, backfilled with an open-graded aggregate prior to installation.

The third system of longitudinal edge drains placed on two of the projects used retro-fitted edge drains defined as those placed after the pavement was in service for a substantial length of time. This was to research the effect of edge drains on older pavements. The system consisted of a geotextile wrapped 10.16cm (four-inches) or 15.24cm (six-inches) diameter pipe trenched into the dense-graded base course at a level directly at the interface of the exposed pavement slab and the base course. The water under the pavement or entering through the transverse or longitudinal joint was assumed to enter the edge drain at that level. The pipe was backfilled with either an open-graded aggregate or material removed during trenching. The fourth system was a fin-type drain, placed vertically in position at the interface of the concrete slab and the base course.

A system known as the Transverse Inter Channel (TIC), featured perforated 5.08cm (two-inches) inside diameter pipe drains placed in the dense-graded base course beneath each transverse joint. Two formats were used: (1) the pipes were placed before construction in narrow shallow trenches, or (2) the pipes were placed after construction (retrofit) by inserting them in a chamber created directly under the concrete pavement at the transverse joint by use of a pneumatic tool known as a “mole.” The TIC drain pipes were encased with geotextile sock on some test sections, and not encased on others.

There were also features resident in the some project structures that were not standard practices (at that time). The first was to have 4.27m (14-foot) driving lanes which were traffic stripped at 3.66m (12 feet) instead of the 3.66m (12-foot) driving lane stripped at the outside edge. This made the outside wheel path 1.52m (five feet) from the outside edge of the pavement, rather than 0.91m (three feet). It was theorized that 4.27m (14-foot) driving lanes would cause less stress at the outside slab corners and edges. The second element existed only on USH 18-151, Iowa and Dane counties. Rock excavation by blasting was necessary during the construction on this facility. The shattered rock was then placed in a 30.48cm (12-inches) layer with a 15.24cm (six-inches) depth of dense-graded base course placed over it on several locations in the east bound roadway. This two layer structure was constructed and had been in place for approximately two years previous to the placement of the concrete pavement.

METHOD OF ANALYSIS

Pavement performance data was collected from the research sections of each project. All projects contained at least one control section and multiple test sections. The control section incorporated design characteristics that were the elements of the WisDOT standard pavement structure at the time of study inception. For this study, the standard pavement structure was an unsealed plain jointed pavement on dense-graded base course. Each test section had at least one research element. The research sections of USH 18-151, Dane County, were included in the analysis computations because the project was constructed in the same year as, and was adjacent to, USH 18-151 Iowa County.

The projects were monitored yearly to determine the Pavement Distress Index (PDI) [1]. This data was derived from personal on-site observations of specific distresses. For PCC, these included slab breaks, distressed joints, cracks, slab surface distress, patching, faulting and longitudinal distress. For AC, these included cracking, raveling, surface distortion, rutting, flushing and patching. The extent and severity of the distresses were weighted and used in a formula to compute the PDI. The distress status of a pavement surface was indicated on a scale from 0 to 100 where the road surface quality decreases with higher PDI values. It was generally accepted that 70 was the threshold PDI value for pavements to become candidates for some form of rehabilitation.

One of the earliest occurring structural PCC distresses observed was transverse joint faulting. Although faulting is usually collected during PDI surveys in increments of 6.4mm (“0.25 inch”), for this research, faulting data in 0.3mm (0.01 inch) increments was collected during separate on-site surveys.

The projects were also monitored yearly to determine the International Roughness Index (IRI) for both PCC and AC pavements. Several factors related to the IRI will be referred to for significance or comparison in this report:

(1) There was an IRI rehabilitation threshold of 3.00 IRI for Interstate and Primary Arterials [2].

(2) In a IRI range of 1.50 - 3.50, a difference of 0.50 IRI in an individual year between test and control sections would be considered significant [2].

(3) The new construction of PCC surfaces for 1996 had an average IRI of 1.45, and for AC surfaces, an average of 1.04 (per WisDOT data).

Statistical “paired t-tests” [3] were performed at the 95 % confidence level on control section and test section data for PDI, faulting and IRI. Although the paired-t test does not define a quantitative difference between the test section and the control section, it does define a qualitative relationship. The results were specific to the project and comparisons of statistical test results between projects should be made with qualification. When the paired t-test result was less than a computed critical “ t-score” value, the test section results were considered “SIMILAR TO (those of the) CONTROL" section. However, when the test section paired t-test result exceeded that of the critical "t-score" value, the test section values were considered significantly "DIFFERENT" than those of the control section.

To further describe how the "significantly different" results of the test sections were related to the control section, the data points of each test section were summed and a list developed. The sums for the test sections and control section were then ranked on the list from most to least beneficial. The sums of the "similar" test sections were found to be clustered adjacent to that of the control section sum. The "different" test sections then occupied the ends of the list as "different /worse" (the least beneficial) or "different /better" (the most beneficial), depending on their ranking (Table 8).

It was felt that insight with respect to PDI, faulting and IRI could be gained if the data from the various data bases were ranked according to the measurements from the most beneficial value to the least beneficial. A table was developed that listed the RANKING of the 1997 PDI data for all of the primary project research sections (Table 3). This table also listed selected structural characteristics for each test section. Similar ranked tables were developed for transverse faulting data (Table 4) and IRI data (Table 5).

Falling weight deflectometer (FWD) testing was performed on the PCC projects of "USH 18-151 Drain" and "USH 18-151 Dowel" in 1994 [4], and on the AC projects of STH 60 and STH 167 in 1993 and 1995 [5]. The FWD measured the amount of slab support provided by the various layers in the pavement structure in general and, for this research study, of the base support in particular.

ANALYSIS RESULTS

(A) PRIMARY PROJECTS

(A1) <u>Asphalt Stabilized Open-Graded Base Course, Dowels and Select Embankment</u>

The monitoring of the primary projects indicates that there had been very little distress over the life of the program. This low level of distress resulted in very low PDI values. The primary projects in this study, built in 1987 and 1988, have an average PDI of 10 with a range from zero to approximately 26 (Table 3). The only distress which had been observed commonly on all the projects had been transverse joint faulting. The average faulting for the test sections of the primary projects was very low and always less than 6.4mm (0.25 inch) (Table 4). The PDI survey manual weighting system indicates that the lowest increment for faulting is 6.4mm (0.25 inch) [1] and that transverse joint faulting can add a range of six to eleven points to the PDI. Therefore, the major contributor to the PDI was the most common type of distress on the primary study projects; transverse joint faulting.

The ranked data values of PDI indicated that test sections with similar design elements appear to group together and be dominant among test elements. The test sections which had the dominant elements of dowels, asphalt stabilized open-graded base course and select embankment (USH 18-151, Iowa County and Dane County) had better PDI values (Table 3). The results were similar when the faulting survey results were ranked (Table 4).

It was seen in the rankings of PDI and faulting data that test sections which had these dominant elements dominated the lower value end of the PDI range. However, when dowels, asphalt stabilized open-graded base course or select embankment were found in combination in a test section structure, the test section ranked similar to test sections with only one of the dominant elements. This implies that the strong effect of these elements was not additive or cumulative, but was individual and concurrent; that the effect of a combination of these elements was no greater than the effect of any one of the elements.

Ride quality was measured using International Roughness Index (IRI) values. The 1996 ride quality of the test sections having one or more of these three dominant elements was within a range of 1.47 IRI to 1.95 IRI, compared to the 1996 PCC new construction average of 1.45 IRI [6] (the 1997 new construction average IRI was not available at the printing of this report).

The average section IRI results ranked in Table 5 show that between the best test section IRI (STH 29, test section 3) and the last test section which lists a design element (STH 18/151, test section 4) there was a range of 0.46 IRI. The IRI threshold of significance is 0.50 IRI, and this difference was not larger than that. This appears to support the finding that there is no greater significance whether an individual test section had one of the dominant elements or a combination of these elements.

Statistical paired t-testing performed on the data from PDI, transverse faulting and IRI indicated that test sections having dowels, asphalt stabilized open-graded base course and select embankment were significantly better on the individual projects (Table 8). The effect of any of these three dominant elements was much greater than, or masked the effect of any other research element in the same test section. This is seen on each of the three ranking tables (Tables 3, 4 and 5) where the base feature, edge drain type or sealing of the transverse joint do not exhibit any apparent pattern.

The effect of other research elements can be seen on the ranked tables (Table 3, 4 and 5) below the grouping of test sections having the three dominant elements. In this part of the tables, it can be seen that test sections with open-graded base courses (other than asphalt stabilized), rank higher than test sections having dense-graded base course.

(A2) <u>Analysis of Falling Weight Deflectometer Testing Of PCC Pavements</u>

Falling weight deflectometer (FWD) measurements on USH 18-151 Iowa County and USH 18-151 Dane County indicated that the majority of sections would be considered uniformly supported. There were indications of non-uniformly supported slabs on sections of two projects.

The first was the cement stabilized open-graded base course test section of USH 18-151 Iowa County which also had undoweled, sealed transverse joints. The second was the non-stabilized open-graded base course test section of USH 18-151 in Dane County which had doweled and unsealed transverse joints. However, these indications were based on a limited data set from each section.

(B) SECONDARY PROJECTS

(B1) PCC Pavements

Similar positive drainage projects constructed subsequent to the beginning of the primary research study, and having similar structures, were experiencing similar levels of pavement performance (Table 6).

In 1991, the WisDOT, in conjunction with the Federal Highway Administration (FHWA) developed a demonstration and research project. WisDOT , hosted the "1991 Open-Graded Base Course National Open House". The project featured four PCC pavement research sections and control sections, and two AC pavement research sections with control sections consisting of rehabilitated existing pavements..

Of the four PCC pavement research test sections, three were open-graded base courses using the Wisconsin #1 gradation: non-stabilized, cement stabilized: and asphalt stabilized. The fourth section had the "New Jersey" open-graded base course (similar in gradation to the WisDOT open-graded base course #2). All pavement surfaces had 4.27m (14-foot) driving lanes and doweled transverse joints. The control section was on an existing bridge approach with the pavement on a dense-graded base course structure.

After six years of monitoring, the PCC pavement test sections had PDI's of 0, with distresses (including faulting) being almost non-existent. The ride quality of the PCC test sections were within a range of 1.47 IRI to 1.95 IRI, compared to the 1996 new PCC construction average of 1.45 IRI [6] . The east and west PCC control section had PDI's of 11 and 16 respectively, with an average faulting of 2.54mm (0.10 inch) and an average IRI of 2.62. The conclusion after six years of monitoring was that the test sections were providing excellent pavement performance to date, but that monitoring of the test sections should continue until the distress levels increased to the point of being able to provide a basis for making definitive conclusions.

It was decided in 1991 to determine the effect of shortened slabs (approximately 3.05m (ten feet long)) on transverse joint faulting. The pavement chosen for this portion of the study was located on IH 43 in Walworth County in southeastern Wisconsin. It was a PCC pavement without dowels, on a dense-graded base, with no positive drainage and an average transverse joint faulting of 6.6mm (0.26 inch). Three rehabilitation operations were proposed. Slab length was dictated by the random slab length sequence of 3.66m/3.97m/5.80m/5.48m (12-foot/13-foot/19-foot/18-foot). The first operation was to cut the two larger slabs in half (performed in 1991). It was theorized that the resultant shorter slabs would result in an immediate reduction in faulting, or lower IRI. Moreover, the shorter slabs were theorized to be less susceptible to subsequent faulting. The second operation was to retro-fit edge drain pipe at the base / slab interface at the edge of shoulder (performed in 1993). This theoretically would remove water from the base and retard subsequent faulting. The third operation was to have the pavement in the test sections diamond ground (performed in 1993) to an IRI comparable to new construction. After years of monitoring (1995), it was revealed that the subsequent faulting rate for the test sections was essentially the same as for the control section, regardless of whether the long slabs had been cut or edge drains had been installed. Faulting went from a zero profile to an average of 2.5mm (0.10 inch) in that period (Table 6). It was concluded that these operations did not provide adequate rehabilitation.

In 1989 it was decided to determine whether severely faulted PCC pavement could be rehabilitated using TIC joint drains, various edge-drain formats and diamond grinding to achieve a new construction profile. A section of IH 43 in Ozaukee County in eastern Wisconsin was chosen for this portion of the research. This PCC pavement was without dowels, on a dense-graded base, had no positive drainage and had average transverse joint faulting of 7.1mm (0.28 inch). The drainage formats included draining to an outside edge drain or direct drain ("daylighting") to both the outside ditch and the median. In 1989, the TIC drains were installed and the driving lane of the test and control sections was diamond ground. After six years of monitoring it was determined that 45 to 82 percent of the pre-grind faulting had returned for both the test and control sections (Table 6) and could be easily felt from within a passenger vehicle (when greater than 3.8mm (0.15 inch)). It was concluded that installation of the TIC drains had not retarded faulting or kept it from reaching noticeable levels.

(B2) <u>AC Pavements</u>

The primary study plan contained no initial mandate to research AC pavement structures with open-graded base course combinations. However, there were three secondary projects which featured pavement structures with AC pavement surface and positive drainage elements of open-graded base course in various formats (Table 7).

STH 73 in Dodge County in the south central part of the state, was an early attempt to determine possible benefits of open-graded base course and problems during construction. The project was constructed in 1985 using a structure of 10.1cm (4-inches) of asphaltic concrete surface with a non-stabilized open-graded base course separated from the subgrade by a geotextile. The edge drains consisted of perforated pipe placed at the bottom of a geotextile wrapped, open-graded base course filled trench located at the outside edge of the pavement. A control section with a standard dense-graded base course structure was sited adjacent to the test section.

Though the site was rural and had a low truck loading, the project has added to the needed base of knowledge. Several construction difficulties were encountered on the test section which resulted in severe distress when the asphalt base course was paved. The non-stabilized open-graded base course was placed only 45.72cm (18-inches) wider than the intended pavement. Although paving was performed by a tracked paver, the non-stabilized open-graded base course tended to roll out from under the tracks due to the narrow width of the non-stabilized open-graded base course and created a windrow surface effect. This in turn resulted in poor ride quality for the test section pavement. A variable 25.4mm (one-inch) to 50.8mm (two-inches) of asphalt was added to the asphalt base course to alleviate the poor ride quality before the asphalt pavement surface course was added. The 1997 IRI value was not available. In 1997 the control section PDI was 36 while that of the test section was 49. The test section PDI was higher due to more block cracking at the centerline than that of the control section. It would appear that the added asphalt layer on the test section surface did not enhance the strength. Contemporary construction practices now provide for the open-graded base course layer to be placed wide enough to adequately support a tracked paver.

The secondary project "Open-Graded Base Course National Open House," mentioned in the previous portion of this report, also had demonstration AC pavement test sections on asphalt stabilized open-graded base course using Wisconsin #1 and dense-graded base course. The AC pavement test section was on STH 73 adjacent to the project site in an area that served primarily rural farm traffic, but did average one percent heavy truck traffic. The control section was on a local road. The control section had mostly rural traffic and no heavy trucks. However, the facility attracted significant traffic because it had a bridge that is one of the few crossings of STH 151 in the area. Although the asphaltic mix and thickness were the same as the STH 73 test section, the width was less since it was a local road. There were no construction difficulties on either section. In 1997 the asphalt stabilized open-graded base course test section had a PDI of 19 while the dense-graded base course control section had a PDI of 30. The control section had greater transverse cracking and patching of the edges, possibly due to narrower roadway width. The asphalt stabilized open-graded base course test section had an IRI of 1.65 after five years of service (compared to a 1996 new AC construction IRI average of 1.04). These values indicate that the asphalt stabilized open-graded base course test section had provided acceptable pavement performance.

Two other secondary AC pavement projects were constructed in 1991. However, these projects had a recycled asphalt binder course and several different formats of open-graded base courses compared to a control structure having dense-graded base course. The first project was on STH 60, a divided highway, near a then-developing commercial area in Washington County, west of USH 41. This project had two test sections in the west bound (WB) direction and a test section and control section in the east bound (EB) direction. A difficulty with subbase / subgrade stability was encountered during initial construction. It was not noted whether the extent of the problem included lanes in one or both directions.

In 1997, the asphalt stabilized open-graded base course section had the best PDI value of the project, although the difference was only marginally better than the open-graded base course #2 test section (Table 7). The 1997 PDI results indicated the distress in the dense-graded base course control section and the non-stabilized open-graded base course test section was severe, with the PDI values exceeding the rehabilitation threshold. The field data indicated block and longitudinal band cracking to be the major distresses. It was difficult to reconcile the severity of the control section PDI with the indication of excellent IRI. The 1997 IRI results indicated the test sections had adequate ride quality. It was implied by the data results that the asphalt stabilized open-graded base course structure appears to have the potential for beneficial pavement performance. This project poses a difficulty for analysis in that one individual test section did not possess both the most beneficial PDI and IRI data measurement results.

The second project was on STH 167, a two-lane urban residential arterial in Washington County, east of STH 145. A TIC drain system was placed beneath the pavement with saw cuts through the pavement of the control section to promote the drainage of the structure. Previous to 1997, the test and control section had similar PDI performance. Statistical paired t-testing confirmed this similarity. The 1997 pavement distress data indicated that extensive band cracking had been generated at the control section sawed cuts and had amplified the PDI. The 1997 IRI data results show the control section to be performing significantly better than the test section, regardless of the band cracking. This poses a difficulty as with the previous project, where one test section has the best PDI value while another has the most beneficial IRI value. This difficulty points to the need for further projects with a larger number of test sections to help define differences between the test sections.

Falling weight deflectometer testing was performed in 1993 and 1995 by different consultants.[5] The results were different for the two years because they were directly related to the conditions that existed at the time of the test operations. The results indicated that the open-graded base course-#2 test section on STH 60 had significantly greater remaining life than the other test sections. On STH 167 the non-stabilized open-graded base course test section was indicated to have significantly greater remaining life than the control section. However, the FWD results were tempered by the statistical paired t-testing not being comparable for beneficial aspects between the test section and control section. The open-graded base course-#2 test section was statistically better for PDI and the control section being better for IRI.

The analysis for the AC portion of this research has been shown to be hampered due to the few test sections available and the diversity of research concepts attempted within those few. Whereas the PCC portion of this research now has many test sections in place and a large historical data base, the AC portion had very few test sections and a small data base. It would be as advantageous to develop a structured research study for positive drainage of AC pavements similar to the PCC portion of the study to provide adequate test section redundancy and more reliable results.

EFFECTIVENESS OF POSITIVE DRAIN FEATURES

One of the objectives of the research was to determine which features were most effective in draining excess water from the pavement structure,

(A) BASE COURSE MOISTURE

This aspect of the study was intended to determine the relationship between rainfall events and base course moisture. Generally, not all sensors in an array indicated a saturation condition during or after a rainfall. It was anticipated and confirmed that the sensors located adjacent to the edge drains would experience saturation. During substantial rain events (at least 12.7mm (0.50 inch)) the sensors near the edge drain trench (outer edge of the driving lane slab) would first begin to indicate a moisture change and rise to saturation or near saturation. A small number of sensors at the inner edge of the driving lane slab were the next to respond followed by very few of the sensors at the mid-slab position. The return of the sensors to the non-saturated state varied greatly and was dependent on the extent and duration of the rainfall event.

It was determined after the first winter season that the sensors were critically sensitive to salt contamination. By department policy, the pavement surfaces of state trunk highways are heavily salted to achieve a clear pavement condition, if possible. The resulting salt brine penetrating to the sensors contaminated the dense-graded base course surrounding the sensors, rendering the sensors unusable after the first salting season. Thus a reliable analysis was not possible in succeeding years and this aspect of the study had to be dropped.

(B) OPEN GRADED BASE COURSES

It was not possible to differentiate between the various types of open-graded base courses by means of the data generated by the base course moisture sensor monitoring. There were no observed areas of the pavement where the surface distress could be linked to insufficient drainage, regardless of the drainage capabilities of the structure. Considering the very limited amount of observed distress, it was not possible to differentiate which drainage systems were most effective in draining excess water from the pavement structure. However, the 1997 rankings of the PDI, faulting and IRI measurements (Tables 3, 4 and 5) imply that an undoweled pavement with a positively drained structure appeared to be more beneficial than an undoweled dense-graded base course structure that had no drainage feature.

(C) PRIMARY STUDY EDGE DRAINS

The test sections of most primary projects primarily used an edge drain with a perforated pipe in the bottom of a geotextile wrapped trench filled with open-graded base course aggregate. This format was compared to a dense-graded base course structure, usually undoweled, and having no edge drain (the WisDOT standard at the time). Two of the projects compared fin drains and retrofit wrapped pipe systems, and similarly compared them to a dense-graded base course structure. All of the drain systems appear to be draining adequately at this time. The edge drains should continue to be observed since definitive distress changes may be manifest after sufficient elapsed time.

(D) RETROFIT EDGE DRAINS

The project on STH 18-151 westbound lanes, Iowa County, was created to determine whether retrofit-edge drains would inhibit or eliminate the return of transverse joint faulting. The project site had an original structure consisting of undoweled PCC pavement on dense-graded base course. Two test sections and one control section were constructed. One test section had retrofit wrapped-pipe drains and the other had retrofit fin-type drains. The control section had no drains. The pavement had been in service for five years before installation of the drains and was moderately faulted. In 1988, the edge drains were installed and the pavement was diamond ground to eliminate the faulting. After two years of faulting measurements the results indicated that the faulting in all sections had returned to the pre-grind level. It was concluded that retrofitting of either pipe or fin edge drains did not inhibit the return of transverse joint faulting [7].

A retrofit drain system was also used on STH 50 even though the project was new construction. The fin-type drains were used on two test sections, the wrapped pipe system was used on two test sections, and no edge drain was used on two others as a control. The PDI and faulting measurements of the test sections were not significantly better than those of the dense-graded base control section (Tables 3 and 4). This implies that the test sections with retrofit edge drains were not significantly better than the non-drained dense-graded base control section.

(D1) Retrofit Drains and Shortened Slabs

On IH-43, Walworth County, a research project was established to determine whether shorter PCC pavement slab lengths and retrofit edge drains would result in the elimination or reduction of the rate of transverse joint faulting. The pavement structure was an undoweled PCC pavement on dense-graded base course. A test section was established where the long slabs of the random joint sequence 3.66m/3.97m/5.80m/5.48m (12-foot/13-foot/19-foot/18-foot) were cut in half. Two other test sections were developed where the long slabs were not cut. All the test sections were diamond ground and retrofitted with a geotextile-wrapped pipe edge drain. A control section was established in close proximity to the original test section. The control section was surface diamond ground, but not retrofitted with edge drains. The statistical paired t-test indicated that the average IRI of the test sections was similar to that of the control section. This implies that the creation of short slab and retro-fitting of edge drains did not eliminate or significantly retard faulting.

The author has observed that the installation trench of retrofit edge drains was often placed near the edge of the pavement without exposing the slab edge and thereby the slab and base interface. This practice often left a vertical barrier of dense-graded base course which would hinder movement of water at the interface to the edge drain pipe.-

(E) TRANSVERSE INTERFLOW CHANNEL (TIC) JOINT DRAINS

Test section 10 on USH 18 / 151, Iowa County, consisted of doweled PCC pavement on dense-graded base course, a 4.27m (14-foot) driving lane, transverse TIC drains and pipe/trench edge drains. The section was located in an area that also had a layer of select embankment. It is difficult to draw conclusions about the TIC drain system from this test section due to the overriding effect of dowels, select embankment, and the 4.27m (14-foot) driving lane. It is assumed that any effect the TIC drain exerted was minimal and masked. However, conclusions are made regarding the TIC system as the discussion proceeds.

The STH 164 Drain project, compared the geotextile-wrapped pipe edge drain system, the geotextile-wrapped pipe edge drain combined with the TIC system and non-drained dense-graded base. At the time of initial construction, the project site was in a relatively rural area. The area subsequently become highly urbanized. Due to the danger of performing survey operations amidst intense urban traffic, no faulting measurements were taken after 1994. The 1997 PDI measurements imply that all the test sections were experiencing a similar levels of distress. The IRI measurements, however, indicate that significant faulting had created a poor ride quality that had exceeded the rehabilitation threshold of 3.0 IRI in the control section and all but one test section. Though this one section did contain the TIC system, a second test section also having the TIC system exceeded the rehabilitation consideration threshold. These results imply that neither the geotextile-wrapped pipe edge drain system nor the geotextile-wrapped pipe edge drain plus TIC system provide pavement performance significantly better than the non-drained dense-graded base sections.

(E1) Retrofit TIC Drains

The research project on IH 43, Ozaukee County, was developed to determine the effect of retrofitting a TIC drain system on a pavement that had previous service. Four “TIC with edge drain” test sections and four control sections without drains were established. Two additional test sections were built to investigate the effect of having each driving lane TIC pipe drain directly (daylight) to the ditches rather than to an edge drain. The retrofit and surface diamond grinding was performed in 1989. The monitored data indicated that the control sections often had similar or better values of PDI or faulting than the test sections. In three of the four cases, the IRI of the control sections exceeded that of the test sections by more than 0.50 IRI, which was considered significant. For these reasons, the presence of retrofitted TIC drains on this project did not appear to be beneficial.

(F) EDGE DRAIN INTERNAL CONDITION AND PERFORMANCE

A limited survey was performed to investigate the internal in-place condition of the pipe in geotextile-wrapped edge drains. The instrument used was the Critical Underground Estimating Scrutinizer (CUES), a small diameter self-illuminating video camera linked to a video monitoring unit. The survey was performed on USH 18 / 151, in Iowa and Dane County which had 15.24cm (six-inches) diameter polyethylene corrugated edge drain pipes. The edge drains were viewed by manipulating the camera approximately 41.15m (135-feet) into the edge drain. The general characteristic of the edge drain appeared to be that of undulating rises and dips, with pools of water in the dips. In many locations there was gravel in the pipe which could not have entered through the moisture slits and was assumed to have entered the pipe due to handling during construction. In a few instances, the camera could not go forward because the pipe was deformed to some degree, either vertically or horizontally. A camera location was approximated from the length of the camera cable used. These locations were investigated and, for the majority, there was no apparent observable surface reason for the crushing. In a very few locations, the pipe crush was due to sign posts or guard rails driven near or through the edge drain pipe. In every instance the grass or the soil at the edge of the outfall apron had shown signs of water flow and there was no apparent proximal pavement surface distress. It was assumed that the conditions viewed in the limited survey were representative of the prevailing conditions. The conclusion was that the dips in the pipe, the aggregate in the pipe, the standing water or the narrowing of the pipe had not caused pavement structural problems in the immediate area up to that time.

All of the 204 outfalls on the USH 18 / 151 Iowa and Dane County project were surveyed from 1989 to 1994 for evidence of water exiting the system and rodent entry. These survey categories included evidence of outfall flow, debris on the outfall aprons, adequate apron pitch, presence of the rodent screen, and debris held in back of the rodent screen. Outfall flow was also determined by the distinctive pattern of grass at the outlet. Using these indicators, all outfalls were seen to be operative.

Rodents would often enter the drain system as evidenced by rodent nests washed down to the outfalls during heavy rain events. Twenty-five percent of outfalls with screens had rodent nest material behind the screen. The outfalls were thought to be entered at the rodent screen slot because the screen slot was large and the screen did not fit tightly against the outlet hole. It was assumed that the presence of rodent nests inside the edge drain would pose a significant problem to effective drainage. However, no drain outfall was found to be inoperative for any cause other than being covered during addition of gravel to the shoulder during regular maintenance operations. The majority of debris on the outfall was grass clippings.
Only seven percent of the concrete outfall aprons were level or had a minimal upward longitudinal pitch where apron debris could have affected water flow. It was concluded that the edge drains have been functioning to an adequate degree.-

SHOULDER/PAVEMENT DIFFERENTIAL (SUBSIDENCE)

Shoulder subsidence describes the differential of the paved shoulder surface either above or below the pavement slab surface. Subsidence was measured at the interface of the shoulder and the pavement slab at the transverse joint and at mid-slab. It was found (in 1996) that the differential was an average of 4.8mm (0.19 inch) below the pavement surface at the transverse joint and mm 4.1mm (0.16 inch) at the mid-slab. The Kentucky Transportation Center (KTC) stated [8] in 1993 that “a difference of more than 76.2mm (three-inches) between the pavement and shoulder (surfaces) can contribute to severe traffic accidents ...“. Therefore, it was concluded that shoulder subsidence is not a problem on any of the primary projects of this research study.

PCC TRANSVERSE JOINT SEALING AND JOINT CONDITION

Transverse joint sealing of concrete pavements was considered an issue before the study was begun. A traditional belief held that sealing of the transverse joint retarded or prevented joint deterioration and subsequent faulting from taking place at the interface of the PCC slab. The sealing of transverse joints as a means of benefiting pavement performance was being researched in a prior WisDOT project [9] which ended during the course of this study. The conclusion of that research was that transverse joint sealing did not benefit pavement performance and therefore was not cost effective. A WisDOT policy was initiated at the conclusion of that study which prohibited sealing transverse joints in state trunk highway pavements except in narrowly defined circumstances[10].

However, investigating the efficacy of joint sealing was one of the original study objectives which determined the test section format of this project. When a test section research format was determined, a redundant test section featuring sealed transverse joints was also created. The data results of this present study support the conclusion of the prior study. When the data results of PDI, faulting and IRI for the primary projects were ranked (Tables 3, 4 and 5), the effect of sealed transverse joints did not appear to have noticeable effect or benefit.

Cores were taken from the primary projects on selected locations of test and control sections. These cores were centered on the transverse joint. No distress was seen on the surface of the coring sites prior to the coring. No deterioration was seen on the concrete portion of the cores or core holes. No deterioration was seen at the interface of the open-graded base layer and the concrete slab in non-stabilized open-graded base course, cement stabilized open-graded base course or dense-graded base course test sections. However, in the asphalt stabilized open-graded base course test sections, the asphalt-stabilized portions of the cores did show minimal stripping (Figure 2). This stripping occurred both at the top and bottom of the 10.16cm (four-inches) asphalt-stabilized layer up to a maximum of 63.5mm (2.5-inches) immediately adjacent to the joint. Loose asphalt-coated aggregate which was found in the core hole appeared to be coated aggregate on which the asphalt bond had weakened. The stripping didn't appear to have caused observable surface distress in the pavement area next to the core. However, the presence of stripping raises some doubts regarding the long term efficacy of asphalt stabilized open-graded base course.

Two cores were taken from test sections that utilized the TIC drain system. The corrugated drainage pipe was found in one of the holes at approximately 50.8mm (two-inches) from the slab joint crack. It was assumed that the system was draining the joint crack adequately for this joint. In the second core hole bottom no trench area of small open-graded aggregate or corrugated pipe was found. The core hole bottom was excavated to a depth of approximately 50.8mm (two-inches), but no pipe was found. Though it was possible that the slotted pipe or trench was adjacent to the core hole, non-intersection of the pipe or pipe trench in the core hole implied that positive drainage was not possible.

COSTS

At the inception of this research study, the standard PCC pavement structure was a plain jointed slab with an option for dowels if considered warranted by traffic loadings. It is the present policy of the WisDOT to have dowels in all PCC pavement structures. The WisDOT also presently encourages the use of positive drainage with open-graded base course [11].

The stabilized open-graded base course cost figures below were compiled from 1997 construction cost data. The roadway characteristics include for 1.61km (one mile) of two-lane doweled pavement structure 7.93m (26-foot) wide with 20.32cm (eight-inches) of PCC on 10.16cm (four-inches) of open-graded base course on 10.16cm (four-inches) of dense-graded base and edge drains.

For:

Asphalt stabilized open-graded base course	$ 393,000 per 1.61km (one mile)
Cement stabilized open-graded base course	$ 396,000 per 1.61km (one mile)

Due to lack of data, costs for doweled pavement structures using non-stabilized open-graded base course, dense-graded base with TIC, and non-doweled pavement systems using the TIC system with asphalt stabilized open-graded base course alone were not available. The dense-graded base course cost figures were from 1997 construction data and consist of 1.61km (one mile) of a two-lane structure, with 20.32cm (eight-inches) of doweled PCC on 15.24cm (six-inches) of dense-graded base.

Dense-graded base	$ 300,000 per 1.61km (one mile)

On the basis of the above cost data and the measured and analyzed historical performance data, dense-graded base with doweled pavement would be as structurally effective and more cost effective than asphalt stabilized or cement stabilized open-graded base course with doweled pavement.-

The initial thrust of this research was to determine the efficacy of positive drainage on PCC pavement structures. However, the two dominant elements seen from the test section data measurements were (1) asphalt stabilized open-graded base course and (2) doweled transverse joints. The research gives strong indication that individual effects of dowels and asphalt stabilized open-graded base course were equal. However, the research also indicates that in combination the effects of these elements were not additive. The indication of powerful and equal influence shown by test sections using dowels and test sections using asphalt stabilized open-graded base course questions the need to have both elements in the same pavement structure. Historical data sets were analyzed using economic depreciating methods comparing a jointed doweled PCC pavement on an asphalt stabilized open-graded base course and dense-graded base course, and a jointed undoweled PCC pavement on dense-graded base course. The analysis indicated that the addition of asphalt stabilized open-graded base course would require an additional 9 years of adequate pavement performance to maintain a positive cost-benefit ratio. If dowels are added to the dense-graded base course pavement structure, only 1 to 2 years of additional adequate pavement performance would be required to reach that same positive cost-benefit ratio.

CONCLUSIONS

The following conclusions can be drawn from the analysis of the research results:

1. Three design elements had dominant effects on the measurements which were significantly greater than the effect of any other research element. These three dominant elements were the presence of (1) dowels, (2) asphalt stabilized open-graded base course (3) 30.48cm (12-inches) of select embankment for sub-base material on USH 18 / 151, Dane and Iowa Counties.

2. A combination of more than one of the three dominant elements appears to have no greater beneficial effect than any one of the elements individually. It appears that the beneficial effect of a combination of these dominant elements was not cumulative. The effect of any one of the three dominant elements was intense enough to mask the effect of any other research elements used on the test section.

3. The inclusion of the 30.48cm (12-inches) of select embankment on USH 18 / 151, Dane and Iowa Counties was a practical on-site dispersal of shot rock. This would not be considered a construction option for future projects since the presence of the shot rock was not a common circumstance.

4. Coring of the PCC transverse joints indicated no joint deterioration for any structural system, except for marginal stripping of the aggregate on the asphalt stabilized open-graded base course layer of test sections. The minimal asphalt cement stripping of the aggregate on the asphalt stabilized open-graded base course layer did not appear to cause surface distress or distress in the PCC slab directly above. However, the presence of stripping raises a concern about the long term efficacy of asphalt stabilized open-graded base course.

5. Dense-graded base course with doweled pavement appears to provide pavement performance equivalent to open-graded base course with doweled pavement and can be constructed with greater economy.

6. Dense-graded base with doweled pavement was shown to be as structurally effective as asphalt stabilized open-graded base course with doweled pavement.

7. Test sections with structures having asphalt stabilized open-graded base and without doweled transverse joints appeared to provide better performance than test sections with structures having non-stabilized open-graded base or cement-stabilized open-graded base and without doweled transverse joints..

8. If WisDOT continues to use non-stabilized open-graded base course, then base #2 should be considered as it provides adequate drainage, is more economical to produce, and can withstand construction traffic.

9. There was very little obvious distress on any of the pavement surfaces. This made the PDI values very low with little margin for comparative differences.

10. The general intensity of transverse joint faulting was low. However, the presence of faulting was the major contributor to the PDI.

11. Pipe edge drains appeared to provide adequate service despite profile dips, the presence of aggregate, standing water, crushing of the pipe, or the presence of rodent nests or grass clippings on the outfall aprons.

12. Test sections with the pipe / aggregate / geotextile-wrapped trench edge-drain system or the fin drain system appear to be performing adequately at this time. However, the small number of test sections for the latter precludes a definitive comparison.

13. Retrofitting of edge drains was not effective in preventing or reducing the progression of faulting.

14. Retrofit edge drain test sections did not provide significantly better pavement performance than dense-graded base test sections without edge drains.

15. Short slab lengths in combination with retrofitting edge drains was not effective in reducing faulting.

16. The TIC drain system did not appear to provide significantly better pavement performance then the dense-graded base structure system.

17. The asphalt stabilized open-graded base course test sections on the secondary AC pavement projects appeared to provide better pavement performance than the dense-graded base sections. However, the number of secondary AC test sections was too few and lacking in redundancy to provide definitive results.

18. Shoulder subsidence does not appear to be a problem on the pavements of the study projects.

19. Test sections with sealed transverse joints did not provide a significantly greater benefit than those with unsealed joints.

RECOMMENDATIONS

1. It is recommended that the existing study be evaluated for five more years to determine possible long range benefits of open-graded bases which are not apparent at this time.

2. There appears to be no pavement performance benefit by using open-graded base course #1 or any stabilized open-graded base course when dowels are used. Until the definitive results for open-graded base course are available, it is recommended that Wisconsin #2 open-graded base be given serious consideration for all open-graded projects, considering its drainage adequacy, trafficability and production cost effectiveness compared to Wisconsin #1 open-graded base.

3. Pavement management data files should be reviewed for projects that used AC pavement over open-graded base. If the project data is lacking, it is recommended that technology advancement projects be developed to determine the efficacy of AC pavement over open-graded base.

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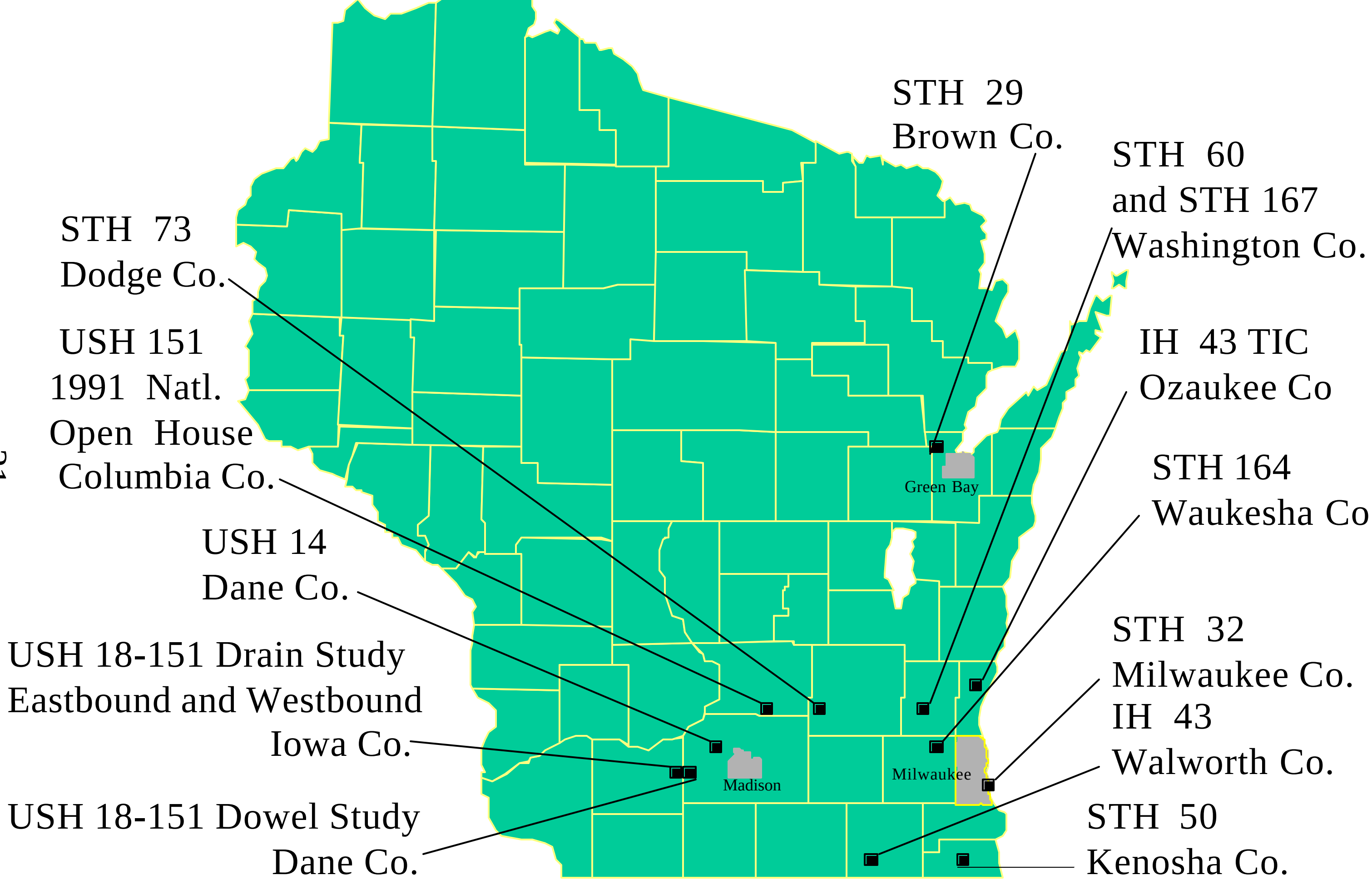
FIGURE 1 PROJECT LOCATIONS



file: FIG1.1 .ppt

FIGURE 2.

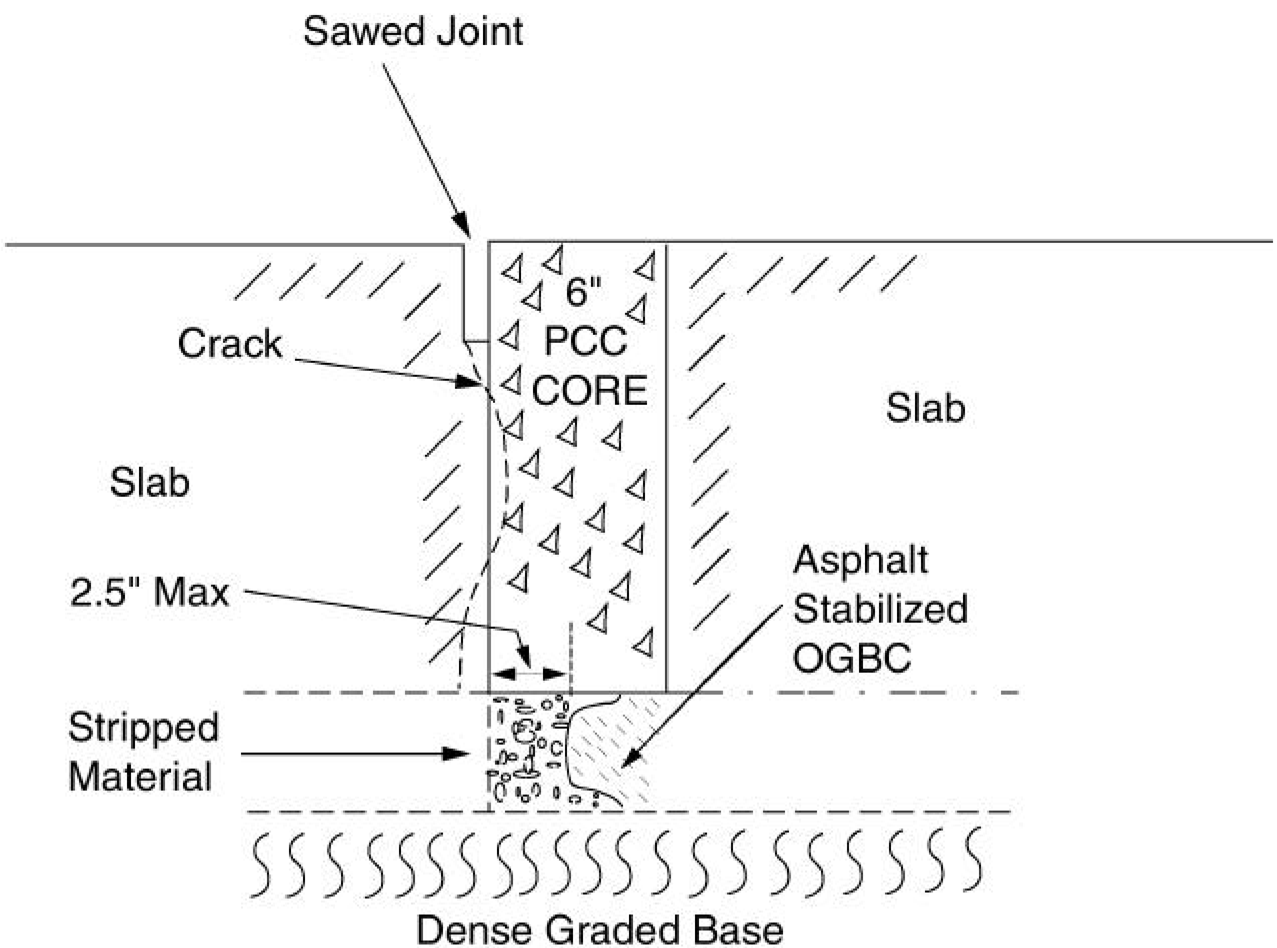

Sawed Joint
6"
PCC
CORE
Crack
Slab
Slab
2.5" Max
Asphalt
Stabilized
OGBC
Stripped
Material
Dense Graded Base

TABLE 1 PRIMARY PROJECTS - TEST SECTION CHARACTERISTICS

PROJECTS	Total Sect	Base Course WisDOT #1 Stabilization			#2		Transverse Joints			Edge Drains				Dowel Trans Joints	Grind Surface
		AS	CS	NS		DBG	Unseal	Seal	TIC Drains	Std	Fin	Wrapped Pipe	None		
PCC Drain Study															
STH 14	3	1				2		3			2	1			
USH 18-151 Iowa County	13	2	2	2		7	6	7	2	6	1-Retro	1-Retro	3	1	3
STH 29	4			4			1	3			4			2	
STH 50	6					6	3	3			2	2	2		
STH 164	6					6	3	3				2	4		
Dowel Study PCC USH 18-151 Dane County	6	1	1	1		3	5	1		3			3	6	

Notes:

Sect ... control/test sections
AS ... asphalt
CS ... cement
NS ... nonstabilized
DGB ... dense graded
#1 ... permeability = 10,000 feet/day
#2 ... permeability = 500 feet/day

TIC ... transverse joint drains
Std ... standard
Fin ... fin-type
Retro ... retrofitted

file: TestSect1.xls 1

TABLE 2 SECONDARY PROJECTS - TEST SECTION CHARACTERISTICS

PROJECTS	Total Sect	Base Course: Wis DOT#1 Stabilization AS	CS	NS	#2	DGB	Transverse Joints: NJ	No Seal	Seal	TIC	Edge Drains: Std	Fin	None	Retro	Day Light	Grind Surf
PCC																
IH 43 Ozaukee Co	10					10			10	6	5		3		2	10
USH 151 Columbia Co	5*	1	1	1		1	1	5			4		1			
IH 43 Walworth Co	4					4			4				1	3		4
AC																
STH 60 Washington Co	4	1		1	1	1					3		1			
STH 167 Washington Co	2			1		1				1	2					
USH 151 Columbia Co	2*	1				1					1		1			
STH 73 Columbia Co	2	1									1		1			

Notes: oth AC and PCC sections.

Sect … control/test sections
X … quantity unknown
AS … asphalt
TIC … transverse joint drains
CS … cement
Std … standard
#1 … permeability = 10,000 feet/day
NS … nonstabilized
Fin … fin-type
#2 … permeability = 500 feet/day
DGB … dense graded
Retro … retrofitted
NJ … New Jersey gradation

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TABLE 3 **1997 PDI RANKINGS***

PCC TEST SECTIONS AND STRUCTURE FEATURES

PRIMARY PROJECTS *

1997 PDI	Project Code	Test Section	Base Feature	Edge Drain Type	Special Features		
0	STH 29	Control 4	OGB	P	dowels		
0	STH 29	3	OGB	P	dowels		seal tran jt
3	18/151DRAIN	10	DGB/TIC	P	dowels	30.5cm select embank	
6	18/151Dowel	2	ASOGB	P	dowels		
6	18/151DRAIN	6	ASOGB	P			
6	USH 14 (a)	1	ASOGB	F			seal tran jt
6	18/151Dowel	1	CSOGB	P	dowels	30.5cm select embank	
6	18/151Dowel	3	NSOGB	P	dowels	30.5cm select embank	
6	18/151Dowel	4	DGB	N	dowels	30.5cm select embank	
6	18/151Dowel	Control 5	DGB	N	dowels	30.5cm select embank	seal tran jt
6	18/151DRAIN	7	DGB/TIC	P		30.5cm select embank	
6	18/151DRAIN	9	DGB	N		30.5cm select embank	
7	STH 29	2	NSOGB	P			seal tran jt
9	18/151DRAIN	Control 8	DGB	P		30.5cm select embank	seal tran jt
11	18/151DRAIN	5	ASOGB	P			seal tran jt
11	18/151DRAIN	3	CSOGB	P			seal tran jt
11	18/151DRAIN	4	CSOGB	P			
11	USH 14 (a)	2	DGB	F			
11	STH 50	3	DGB	GWP			seal tran jt
12	STH 50	1	DGB	F			seal tran jt
12	STH 50	Control 5	DGB	P			seal tran jt
13	18/151DRAIN	1	NSOGB	P			seal tran jt
13	18/151DRAIN	2	NSOGB	P			
13	STH 164	Control 1	DGB	N			seal tran jt
13	STH 164	2	DGB	WPT			seal tran jt
13	STH 164	3	DGB/TIC	WPT			seal tran jt
13	STH 164	4	DGB/TIC	WPT			
13	STH 164	5	DGB	N			
13	STH 164	6	DGB	WPT			
15	STH 29	1	NSOGB	P			
16	STH 50	2	DGB	F			
16	STH 50	4	DGB	GWP			
16	STH 50	6	DGB	N			
21	USH 14 (a)	Control 3	DGB	N			seal tran jt
24	18/151DRAIN Retro	1	DGB	F		retrofit edge drains	seal tran jt
24	18/151DRAIN Retro	2	DGB	N			seal tran jt
26	18/151DRAIN Retro	Control 3	DGB	GWP		retrofit edge drains	seal tran jt

Note:

(a) constructed in 1987.

* … 1988 construction unless otherwise noted.

WPT … geotextile wrapped pipe placed in trench

GWP … geotextile wrapped pipe plowed into shoulder

N …no edge drains

F… fin-type edge drains

P… pipe/aggregate edge drains

NA … not available

OGB … Open Graded Base

AS … Asphalt Stabilized

NS … Non-Stabilized

CS … Cement Stabilized

DGB … Dense Graded Base

TIC … transverse joint drains

embank … embankment

tran jt …. transverse joint

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TABLE 4 1997 TRANSVERSE JOINT FAULT RANKINGS

PCC TEST SECTIONS AND STRUCTURE FEATURES

PRIMARY PROJECTS **

1997 FAULT*	Project Code	Test Section	Base Feature	Edge Drain Type	Special Features		
0.03	18/151DRAIN	5	ASOGB	P			seal tran jt
0.03	18/151Dowel	2	ASOGB	P	dowels		
0.03	18/151DRAIN	10	DGB/TIC	P	dowels	30.5cm select embank	
0.03	18/151Dowel	3	NSOGB	P	dowels	30.5cm select embank	
0.03	18/151Dowel	Control 5	DGB	N	dowels	30.5cm select embank	seal tran jt
0.03	STH 29	3	NSOGB	P	dowels		seal tran jt
0.03	STH 29	Control 4	NSOGB	P	dowels		
0.61	18/151Dowel	1	CSOGB	P	dowels	30.5cm select embank	
0.61	18/151Dowel	4	DGB	N	dowels	30.5cm select embank	
0.91	18/151DRAIN	6	ASOGB	P			
1.52	USH 14 (a)	1	ASOGB	F			seal tran jt
1.52	18/151DRAIN	7	DGB/TIC	P		30.5cm select embank	
1.82	18/151DRAIN	Control 8	DGB	N		30.5cm select embank	seal tran jt
2.13	18/151DRAIN	9	DGB	N		30.5cm select embank	
2.13	18/151DRAIN	1	NSOGB	P			seal tran jt
2.13	18/151DRAIN	3	CSOGB	P			seal tran jt
2.43	18/151DRAIN	2	NSOGB	P			
2.43	18/151DRAIN	4	CSOGB	P			
2.43	STH 50	1	DGB	F			seal tran jt
2.43	STH 50	2	DGB	F			
2.43	STH 29	2	NSOGB	P			seal tran jt
2.74	STH 29	1	NSOGB	P			
2.74	STH 50	6	DGB	N			
3.34	STH 50	Control 5	DGB	N			seal tran jt
3.65	STH 50	4	DGB	GWP			
3.95	STH 50	3	DGB	GWP			seal tran jt
5.17	USH 14 (a)	Control 3	DGB	N			seal tran jt
5.48	18/151DRAIN Retro	3	DGB	GWP		retrofit edge drain	seal tran jt
5.78	18/151DRAIN Retro	1	DGB	F		retrofit edge drain	seal tran jt
5.78	USH 14 (a)	2	DGB	F			
6.08	18/151DRAIN Retro	2	DGB	N			seal tran jt
NA	STH 164	Control 1	DGB	N			seal tran jt
NA	STH 164	2	DGB	WPT			seal tran jt
NA	STH 164	3	DGB+TIC	WPT			seal tran jt
NA	STH 164	4	DGB+TIC	WPT			
NA	STH 164	5	DGB	N			
NA	STH 164	6	DGB	WPT			

Note: 0.01 inch = 0.30mm
(a) constructed in 1987.
* … Faulting values in millimeters
* … 1988 construction unless otherwise noted.
WPT … geotextile wrapped pipe placed in trench
GWP… geotextile wrapped pipe plowed into shoulder
tran jt … transverse joint
Retro … retrofit edge drains
embank … embankment
NA … not available

OGB … Open Graded Base
DGB … Dense Graded Base

AS … Asphalt Stabilized
NS … Non-Stabilized
CS … Cement Stabilized
TIC … transverse joint drains
N …no edge drains
F… fin-type edge drains
P…pipe/aggregate edge drains

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TABLE 5 **1997 IRI RANKINGS**

PCC TEST SECTIONS AND STRUCTURE FEATURES

PRIMARY PROJECTS *

1997 IRI	Project Code	Test Section	Base Feature	Edge Drain Type	Special Features		
1.40	STH 29	3	NSOGB	P	dowels		seal tran jt
1.44	18/151Dowel	2	ASOGB	P	dowels		
1.58	18/151DRAIN	7	DGB/TIC	P		30.5cm select embank	
1.60	18/151DRAIN	9	DGB	N		30.5cm select embank	
1.63	18/151DRAIN	6	ASOGB	P			
1.64(b)	USH 14 (a)	1	ASOGB	F			seal tran jt
1.64	18/151DRAIN	10	DGB/TIC	P	dowels	30.5cm select embank	
1.64	18/151DRAIN	5	ASOGB	P			seal tran jt
1.65	18/151Dowel	1	CSOGB	P	dowels	30.5cm select embank	
1.69	STH 29	Control 4	NSOGB	P	dowels		
1.78	18/151DRAIN	Control 8	DGB	N		30.5cm select embank	seal tran jt
1.81	18/151Dowel	Control 5	DGB	N	dowels	30.5cm select embank	seal tran jt
1.84	18/151Dowel	3	NSOGB	P	dowels	30.5cm select embank	
1.86	18/151Dowel	4	DGB	N	dowels	30.5cm select embank	
2.03	STH 29	2	NSOGB	P			seal tran jt
2.14	STH 29	1	NSOGB	P			
2.14	STH 50	1	DGB	F			seal tran jt
2.17	STH 50	2	DGB	F			
2.32	18/151DRAIN	3	CSOGB	P			seal tran jt
2.45	18/151DRAIN	4	CSOGB	P			
2.45	18/151DRAIN	2	NSOGB	P			
2.49	STH 50	Control 5	DGB	N			seal tran jt
2.53	STH 50	6	DGB	N			
2.62	STH 164	3	DGB+TIC	WPT			seal tran jt
2.65	18/151DRAIN	1	NSOGB	P			seal tran jt
2.76	STH 50	3	DGB	GWP			seal tran jt
2.78	18/151DRAINretro	1	DGB	F		retrofit edge drain	seal tran jt
2.78	18/151DRAINretro	Control 3	DGB	GWP		retrofit edge drain	seal tran jt
2.83(b)	USH 14 (a)	2	DGB	F			
3.13(b)	USH 14 (a)	Control 3	DGB	N			
3.15	STH 50	4	DGB	GWP			seal tran jt
3.23	STH 164	2	DGB	WPT			seal tran jt
3.26	STH 164	4	DGB+TIC	WPT			
3.56	18/151DRAINretro	2	DGB	N			
3.87	STH 164	Control 1	DGB	N			seal tran jt
4.46	STH 164	6	DGB	WPT			
4.47	STH 164	5	DGB	N			

Note:

* … 1988 construction unless otherwise noted.

(a) … constructed in 1987.

(b) … 1996 IRI; 9 years old in 1996

Other projects were 9 years old in 1997

WPT … geotextile wrapped pipe placed in trench

GWP … geotextile wrapped pipe plowed into shoulder

N … no edge drains

F… fin-type edge drains

P … pipe/aggregate edge drains

OGB … Open Graded Base

AS … Asphalt Stabilized

NS … Non-Stabilized

CS … Cement Stabilized

DGB … Dense Graded Base

embank … embankment

tran jt … transverse joint

file: IRISTRUC.xls 1

TABLE 6 SECONDARY PCC PROJECTS 1997 FAULT, PDI, IRI TEST SECTIONS AND STRUCTURE FEATURES

FAULT 1997	PDI 1997	IRI 1997	Project Code	Test Section	Base Feature	Drainage Feature	Other Special Features
			USH 18-151 COLUMBIA COUNTY				
0.00	0.00	1.95	91 OPEN HOUSE	1	NSOGB	standard	dowels
0.00	0.00	1.72	91 OPEN HOUSE	2	ASOGB	standard	dowels
0.00	0.00	1.47	91 OPEN HOUSE	3	NJOGB	standard	dowels
0.00	0.00	1.61	91 OPEN HOUSE	4	CSOGB	standard	dowels
0.01	11	2.46	91 OPEN HOUSE	Control 5E	DGB	NO edge drain	dowels
0.01	16	2.77	91 OPEN HOUSE	Control 5W	DGB	NO edge drain	dowels
1995	1995	1996	IH 90/94 SAUK COUNTY				
0.04	0.00	1.83	IH 90/94 JOINT FILL	1	DGB	NO edge drain	dowels
0.04	0.00	1.61	IH 90/94 JOINT FILL	Control	DGB	NO edge drain	dowels
1997	1996	1997	IH 43 WALWORTH COUNTY				
0.12	11	2.32	IH 43 RETRO FIT ED	1	DGB	retro edge drain	grind
0.11	11	2.26	IH 43 RETRO FIT ED	2	DGB	retro edge drain	grind cut slabs
0.13	11	2.12	IH 43 RETRO FIT ED	3	DGB	retro edge drain	grind
0.15	76	2.86	IH 43 RETRO FIT ED	Control 4	DGB		
1995	1996	1997	IH 43 OZAUKEE COUNTY				
0.16	20	2.91	IH 43 TIC DRAIN	5	DGB	TIC daylight DL to outside ditch	
0.13	20	2.51	IH 43 TIC DRAIN	6	DGB	TIC daylight DL to outside ditch; PL to median	
0.16	20	2.43	IH 43 TIC DRAIN	Control 1	DGB	NO TIC	
0.14	20	2.74	IH 43 TIC DRAIN	1	DGB	TIC both lanes to outside standard edge drain	
0.19	20	3.21	IH 43 TIC DRAIN	Control 2	DGB	NO TIC	
0.18	20	3.86	IH 43 TIC DRAIN	2	DGB	TIC both lanes to outside standard edge drain	
0.14	11	2.35	IH 43 TIC DRAIN	Control 3	DGB	NO TIC	
0.14	20	2.89	IH 43 TIC DRAIN	3	DGB	TIC both lanes to outside standard edge drain	
0.17	20	2.69	IH 43 TIC DRAIN	Control 4	DGB	NO TIC	
0.15	15	3.92	IH 43 TIC DRAIN	4	DGB	TIC both lanes to outside standard edge drain	

Note:

trans … transverse
TIC … transverse joint drains
NJ … New Jersey gradation
AS … Asphalt Stal
NS … Non-Stabilized
CS … Cement Stabilized

DGB … Dense Graded Base
OGB … Open Graded Base
DL … driving lane
PL … passing lane
standard … pipe in aggregate / wrapped trench edge drain
retro … wrapped pipe placed at slab / base interface edge drain

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TABLE 7 SECONDARY AC PROJECTS 1997 PDI, IRI TEST SECTIONS AND STRUCTURE FEATURES

1997 PDI	1997 IRI	Project Code	Test Section	Base Feature	Drainage Feature
		STH 73 DODGE COUNTY			
49	NA	STH 73	1	NSOGB	pipe/aggregate/wrap trench edge drain
36	NA	STH 73	CONT	DGB	No edge drain
		USH 151 COLUMBIA COUNTY			
30	NA	91 OPEN HOUSE	6CONT	DGB	No edge drain
19	1.65	91 OPEN HOUSE	7	ASOGB	pipe/aggregate/wrap trench edge drain
		STH 60 WASHINGTON COUNTY			
59	2.03	STH 60 WB	1	ASOGB	pipe/aggregate/wrap trench edge drain
66	2.04	STH 60 WB	2	OGB#2	pipe/aggregate/wrap trench edge drain
80	2.12	STH 60 EB	3	NSOGB	pipe/aggregate/wrap trench edge drain
89	0.96	STH 60 EB	4CONT	DGB	No edge drain
		STH 167 WASHINGTON COUNTY			
7	2.71	STH 167	1	NSOGB	pipe/aggregate/wrap trench edge drain
33	2.03	STH 167	CONT	DGB+TIC	SAWED JOINTS OVER TIC DRAINS

Note:

OGB#2 ... WisDOT Open graded base #2
CONT ... control section
TIC ... transverse joint drains
NA ... Not Available
OGB ... Open Graded Base

AS ... Asphalt Stabilized
NS ... Non-Stabilized
DGB ... Dense Graded Base
EB ... East bound lanes
WB ... West bound lanes

file: ACOTHER.xls 1

TABLE 8 PAIRED T-TEST RESULTS

PRIMARY PROJECTS* OF RESEARCH STUDY #87-05
PCC TEST SECTIONS AND STRUCTURE FEATURES

Paired T-Test Results (b)			Project Code	Test Section	Base Feature	Edge Drain Type	Special Feature		
PDI	FAULT	IRI							
B	**B**		18/151DRAIN	7	DGB/TIC	P		30.5cm select embank	
	B		18/151DRAIN	5	ASOGB	P			seal tran jt
	B		18/151DRAIN	6	ASOGB	P			
	B	W	18/151DRAIN	10	DGB/TIC	P	dowels	30.5cm select embank	
			18/151DRAIN	Control 8	DGB	N		30.5cm select embank	seal tran jt
			18/151DRAIN	9	DGB	N		30.5cm select embank	
		W	18/151DRAIN	4	CSOGB	P			
	W	W	18/151DRAIN	2	NSOGB	P			
W		W	18/151DRAIN	3	CSOGB	P			seal tran jt
W	W	W	18/151DRAIN	1	NSOGB	P			seal tran jt
	B	**B**	18/151Dowel	3	NSOGB	P	dowels	30.5cm select embank	
		B	18/151Dowel	2	ASOGB	P	dowels		
		B	18/151Dowel	4	DGB	N	dowels	30.5cm select embank	
	W	**B**	18/151Dowel	1	CSOGB	P	dowels	30.5cm select embank	
			18/151Dowel	Control 5	DGB	N	dowels	30.5cm select embank	seal tran jt
B	**B**	**B**	USH 14 (a)	1	ASOGB	F			seal tran jt
			USH 14 (a)	Control 3	DGB	N			seal tran jt
			USH 14 (a)	2	DGB	F			
B		**B**	STH 29	3	NSOGB	P	dowels		seal tran jt
			STH 29	Control 4	NSOGB	P	dowels		
			STH 29	1	NSOGB	P			
			STH 29	2	NSOGB	P			seal tran jt
	B	**B**	STH 50	1	DGB	F			seal tran jt
		B	STH 50	2	DGB	F			
			STH 50	Control 5	DGB	N			seal tran jt
	W		STH 50	3	DGB	GWP			seal tran jt
	W		STH 50	4	DGB	GWP			seal tran jt
W			STH 50	6	DGB	N			
	B		STH 164	2	DGB	WPT			seal tran jt
	B		STH 164	3	DGB+TIC	WPT			seal tran jt
			STH 164	Control 1	DGB	N			seal tran jt
			STH 164	4	DGB+TIC	WPT			
			STH 164	5	DGB	N			
W	W		STH 164	6	DGB	WPT			
B		**B**	18/151DRAINretro	1	DGB	F		retrofit edge drain	seal tran jt
			18/151DRAINretro	Control 3	DGB	GWP		retrofit edge drain	seal tran jt
			18/151DRAINretro	2	DGB	N			seal tran jt

NOTES: * ... 1988 construction unless otherwise noted.
(a) ... constructed in 1987.
(b) ... empty test section cells indicate "similar to" control
B ... "significantly different/better" than control
W ... "significantly different/worse" than control
WPT ... geotextile wrapped pipe in agg filled trench
GWP ... geotextile wrapped pipe at slab/base interface
TIC ... transverse joint drains
P ... pipe in wrapped aggregate filled trench

F... fin-type edge drains
N ... no positive drainage
OGB ... Open Graded Base
AS ... Asphalt Stabilized
NS ... Non-Stabilized
CS ... Cement Stabilized
DGB ... Dense Graded Base
embank ... embankment
tran jt ... transverse joint

file: TTest2.xls